A GUIDE TO AND AN ABSTRACTED BIBLIOGRAPHY OF AIRCRAFT SIDE-ARM CONTROL STICK RESEARCH

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THESIS

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by

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ABSTRACT

An expanding interest at the Naval Postgraduate School, Monterey, California, in research work on aircraft side-arm control sticks has necessitated the determination of the previous and ongoing projects involved with the development of side-arm control sticks. This paper presents a survey of the English language literature dealing with aircraft control sticks over the period of 1936 to 1971. The result of the survey is an abstracted bibliography of significant literature related to the design and testing of aircraft control sticks and a guide to the literature.

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I. INTRODUCTION

As the complexity and performance of modern aircraft continue to increase, it becomes imperative to consider the improvement of flight control systems. Structural flexibility, weight penalties, and combat vulnerabilities are some of the factors which have given impetus to research and development of the fly-by-wire systems. These efforts have made the electric flight control system a credible alternative to previous control systems. A direct consequence of an electric control system is the facility by which the control stick can be located in various cockpit locations.

The side-arm control stick can offer various advantages over the center control stick. Inflated pressure suits and survival equipment can restrict the center stick movements, a limitation which would be alleviated by a side-arm control stick. In addition, the center control stick requires a great amount of space and tends to obscure the lower control panel area.

The feasibility and desirability of the side-arm control stick have been sufficient to merit an expanding interest in research work on its effectiveness, but prior to extensive research investigations it became apparent that a literature survey should be undertaken to determine the existence of any significant works which could contribute in a meaningful way.

As a consequence, the present study was initiated to survey the English language literature on both center and

side-arm control sticks of conventional aircraft regardless of whether they were part of mechanical, hydraulic, or fly-by-wire systems. The survey encompassed the literature on design and testing procedures as well as results. The major contribution of the literature search is an abstracted bibliography on the subject.

The search included the results of research and development activities, manuals, surveys, reviews, and conference or symposium papers. In addition, an attempt was made to establish who or what organizations have written on the subject; for whom the work was written; the currency of the literature; the accessibility of the literature in terms of its being channeled into index sources; and its availability to various users. Also the study entailed an attempt to recover the published and unpublished literature written on the subject into a working collection of material to be utilized in future research efforts.

A major problem in performing a literature search in the field of aeronautical engineering is that the literature is often quickly obsolete. Thus it becomes necessary to provide a means by which a continual updating of the collection can be accomplished. Even though information sources and services change, expand, and disappear, this study provided as a collateral benefit a basis for identifying significant and continuing sources of information on aircraft control sticks.

This thesis was selective rather than exhaustive and relied on conventional and non-conventional sources of

information. These sources are described and include various abstracting and indexing services, information centers and libraries, engineering societies, serial publications, books, manuals, symposiums, and conferences. For convenience a glossary of the acronyms which will be found in this guide is included on page 40.

II. SOURCES CONSULTED

A. INFORMATION CENTERS AND SERVICES

A search of the various centers and services indicated that there was no centralized source of information on aircraft control sticks, though most of these centers and services were U.S. Government sponsored activities. In addition, the search did not disclose a specific guide, published or unpublished, to the literature on the subject. Two published guides are available to the literature of aerospace science, but these two guides did not divide the field into a finite group that would be helpful for cataloging aircraft control stick literature.

Reference books which were helpful as guides to information on sources were quite comprehensive, and in most cases were fairly up-to-date. These included:

1. A Directory of Information Resources in the United States:

Physical Sciences, Engineering. Science and Technology Division, National Referral Center. Washington, Library of Congress, 1971. 803 p.

2. Directory of Resource and Information Systems.

A listing of centers, services, sources, and systems engaged in collecting, storing and disseminating scientific data and information applicable to aerospace research and technology. Office of Aerospace Research, Washington., Aug. 1961. 259 p.

3. Directory of Federal R & D Installations for the Year Ending June 30, 1969.

A report to the Federal Council for Science and Technology, by the National Science Foundation. Supt. of Documents, Washington, 1970. 1044 p. NSF 70-23.

Of the information centers and libraries discussed in the aforementioned works, a number were significant in providing literature on the side-arm control stick. Most notable among these was the Defense Documentation Center (DDC), Cameron Station, Alexandria, Virginia, 22314, formerly called the Armed Services Technical Information Agency (ASTIA). It is the central depository of the Department of Defense for scientific and technical literature. By regulation, all members of the U.S. armed forces, components of the Department of Defense and their contractors and grantees, are to provide DDC with their reports. Other reports are also received by other U.S. Government agencies and several foreign nations. To all U.S. Military, government industrial organizations, and educational organizations authorized to use its services, DDC compiles and distributes its Technical Abstract Bulletin, a bimonthly abstract journal (TAB) [Ref. 1,3, and 4].

In addition to utilizing its TAB, two other services of the DDC were used in this search. One was its demand Bibliographic searches of a computerized collection. Two report bibliographies were compiled by the DDC for the thesis topic. One bibliography was compiled under the indexing term Aircraft Control Sticks, Fly-by-Wire and the second bibliography was compiled under the term Aircraft Cockpit Simulation. Almost all entries were abstracted and all entries had additional descriptors which provided further subject analysis. A total of sixty-three citations were included in the bibliographies, but a majority of them were out of the scope of the topic. The report bibliographies also excluded important DOD reports cited or obtained elsewhere, which would suggest that the DDC collection was incomplete, or has not been incorporated into the computor bank, or that inaccuracy in the indexing process existed.

A second service of the DDC which was utilized for this search was its Research and Technology Work Unit Information which provided information on going current research projects sponsored by the DOD and is available only to DOD contractors, grantees, and regular established users of DDC products and services. The service is based on approximately 20,882 reports on work sheets consisting of project summaries. Through this service a user can obtain management information on current research, development, test and evaluation of tasks of all Department of Defense components indicating who is doing what kinds of research activities, where, and the funding agency for the project [Ref. 4]. Through this

service it was established that the Air Force Flight Dynamics Laboratory has been the major investigator funding research in flight control sticks.

While the National Aeronautics and Space Administration (formerly the National Advisory Council on Aeronautics) is a very important information center in the field of aerospace science, their activities for the most part have been made available through the Defense Documentation Center. The results of NASA research activities are announced in Scientific and Technical Aerospace Reports (STAR) an abstract journal. Its Scientific and Technical Division assembles the results of world wide aerospace research and development activities. These documents include government, industry research institutes, and university reports, journal articles, and reviews. It also receives new technical literature and specialized reports such as project records, patents, etc. from other U.S. Government agencies, laboratories and institutions supported by private industry and other major sources of aerospace knowledge throughout the world [Ref. 1,3, and 4]. All of these documents are indexed in STAR.

Another inportant center of information is the National Technical Information Service (NTIS), formerly the Clearinghouse for Federal Scientific and Technical Information. NTIS carries out provisions of 15 U.S.C. 1151-1157 relating to a clearinghouse for technical information. Its purpose is to simplify and improve public access to the Department of Commerce publications and to data files and scientific and

technical reports produced by Federal agencies and their contractors. Their functions and activities include collecting research, engineering, study and analysis and certain other kinds of technical reports produced by Federal agencies and their contractors. Some data files on magnetic tapes are also collected. A few reports on control sticks were located through NTIS.

The Advisory Group for Aeronautical Research and Development (AGARD), 64 Rue de Varenne, Paris 7e, France is a NATO group which coordinates research and facilitates the interchange of research and development information through working panels [Ref. 3]. Their publications are announced in STAR and are available through NASA. There was no literature published relevant to control sticks; however, AGARD has reports concerning simulation in aircraft research.

Information obtained from the above sources through the present investigation has been deposited with the Library, Naval Postgraduate School.

B. ABSTRACTING AND INDEXING SERVICES.

An abstracting or indexing service is a regularly published serial which provides multiple access to a diverse body of written works. Examples of access include author, subject, title, sponsoring agency, and report code number indices.

Abstracting and indexing services provided a most important means of surveying the literature on aircraft control sticks. Because these services are serial in

nature and a number of them have continued over a lengthy period of time, the indicies provided a systematic approach to the historical development of the literature on the side-arm control stick. Since the series are issued frequently, they also provided a current and continuing source of information on the subject. Some of the services such as STAR and IAA are even more valuable since they monitor world wide literature on aerospace science, including research on subjects closely related to the side-arm control stick.

The search included a year-by-year hand search of NACA Indices (1915-1947), Science and Technical Aerospace Reports, International Aerospace Abstracts, The Engineering Index, Government Report Index, and Technical Abstract Bulletin. Each index and abstracting service was searched from initial publication to February 1972 and the bulk of the literature on aircraft control sticks, both center and side-arm, were located through these services.

It was found that conventional announcements of currently operational research activities for which no final reports or results have been published take on four forms: letters and announcements; reviews of research and development trends; progress reports; and repositories of descriptions concerning research and development projects. The first three forms are indexed to some degree in the aerospace field, including the side-arm control stick. For instance STAR, TAB, and USGRDR included progress reports of on-going research and development projects. These progress reports, in conjunction

with the DDC work-unit summary requested on side-arm control sticks, provided an excellent overview of the present research work being conducted.

A major difficulty encountered in the utilization of indexing and abstracting services of STAR, IAA, and TAB was that subject terms in the indices were too broad and literature on aircraft control sticks were not consistently located under any particular subject term. A multitude of subject terms were screened which included Flight Control, Aircraft Control, Control Simulation, Controls, Adaptive Controls, Flight Simulators, Manual Control, Human Engineering, and Aircraft Stability. Additionally the subject terms changed from year to year.

Future searches for the purpose of updating will require that the current NASA Thesaurus Alphabetical Update for each current year is consulted prior to the utilization of STAR or IAA. No current thesaurus was available for TAB or USGDR, however a demand bibliography from DDC will provide some subject terms in future searches.

C. TECHNICAL SOCIETIES AND MEETINGS.

Presently there are no known societies, organizations, or institutions performing any research or studies on aircraft side-arm control sticks other than the Air Force Flight Dynamics Laboratory and its contractors, the Naval Postgraduate School, and the USAF Aerospace Research Pilot School (ARPS). However, mention is occasionally made of control sticks by technical societies and special purpose

groups which hold symposia, seminars, industry meetings, and conferences.

No attempt was made to list all those organizations interested in aeronautics which might conceivably be interested in the aircraft control stick. A guide to them and their meetings are described instead.

1. Directory of Engineering Societies and Related Organizations.

New York, Engineers Joint Council, 1970. 252 p. Lists organizations in alphabetical order, citing the organizations address, officers, general data, such as the amount of dues, number of members, publications, meetings [Ref. 3].

2. Engineering and Technical Conventions.

New York, Industrial Relations News, Inc. Annual. Provides a listing of national, regional and state meetings of approximately one hundred technical groups. The publication is organized into three sections: Section One is a chronological listing of meetings, with date, location, headquarters, meeting title, and sponsoring organization; Section Two is an appendix listing, in alphabetical order, of the organizations whose meetings appear in Section One; Section Three is a three-part index by technical field, by location and by sponsoring organization [Ref. 3].

3. Scientific Meetings: A List of Forthcoming Events.

Science Technology Division of the Special Libraries Association. Three times a year. An arrangement by sponsor of meeting or name of meeting [Ref. 3].

4. World List of Future International Meetings.

Part I: Science, Technology, Agriculture, Medicine. Washington, D.C., Library of Congress. Monthly. The basis for inclusion in this serial is that the meeting be internally organized, financed, and/or sponsored, or have significant international participation. International is defined as comprising a body of three or more countries [Ref. 3].

5. Some journals which list local, regional, and national meetings on a regular basis include:

Aerospace Management and Aviation Week and Space Technology.

6. Technical societies and organizations which might in the future engage in studies on the aircraft control stick and were included in the literature search are:

a. Instrument Society of America (ISA)

b. Human Factors Society which holds its annual technical meeting in conjunction with an annual Human Engineering Conference, conducted by the Office of Naval Research.

c. American Institute of Aeronautics and Astronautics. Six to eight national meetings are held annually.

d. The Society of Experimental Test Pilots.

For the purpose of updating the abstracted bibliography, knowledge of a meeting is important only in terms of the papers which are presented and of symposiums or discussions

which took place on aircraft control sticks. Knowledge of these papers are facilitated by a guide to conference papers, Current Index to Conference Papers: Science and Technology. This guide is prepared by World Meetings Information Center, New York, CCM Information Corporation. This publication is published monthly and attempts to reduce the time lag which is incurred by conventional means of abstract publications. The speed with which conference papers are indexed in this work may cause certain reliablity problems and the public-action claims an estimated 5 per cent error [Ref. 7].

D. SUMMARY.

This search entailed a variety of means of locating and recovering literature on aircraft control sticks. Furthermore, a certain number of the recovered works in this search were located only by screening each bibliography cited in literature not only of aircraft control sticks but also in other fields such as human engineering, fly-by-wire, and flight simulation. Nothing was uncovered that indicated that a single source or service would provide a capability which would enable a researcher to conduct a comprehensive search of the literature on aircraft control sticks. Future updating of the abstracted bibliographies provided in this study will have to continue to utilize the same tedious and time consuming approach applied in this search. Therefore, the sources consulted and described in this chapter are considered to be the only currently comprehensive guide to aircraft control sticks.

III. SIDE-ARM CONTROL STICKS

A. HISTORICAL PERSPECTIVE ON RESEARCH.

Research efforts on side-arm control sticks for aircraft began as early as 1956 when a side-arm control stick was tested in a F-106 by Air Force Flight Test Center, Edwards Air Force Base, California [Ref. 2]. Since that time numerous research programs have been conducted and continue to investigate the side-arm control stick. Prior to 1956 few published investigations were conducted on control sticks. Principally, these works were by NACA and provide limited value to the present side-arm control stick investigations.

First serious investigations into side-arm control sticks began in 1957. The principal investigator, the Flight Research Division of the Langley Aeronautical Laboratory, realized that with the advent of a reliable electronic control system the side-arm control stick had increased potential, since stick force characteristics could be varied easily, in contrast to adverse aspects of a hydraulic-power system, in establishing acceptable stick force gradients and stick breakout forces. Furthermore, it was realized that aircraft would encounter larger and more abrupt accelerations, as well as pilot induced loads, which would adversely affect the pilot's ability to control an aircraft adequately [Ref. 6]. Ground tests and experimental flights were conducted with side-arm controllers and the desirability and the

feasibility of the side-arm control stick was clearly established. However, there existed a lack of installations in operational aircraft and serious considerations were limited to research aircraft and space vehicles encountering zero G environments.

The advancement of highly reliable fly-by-wire systems and the combat losses in the Vietnam War stimulated a significant amount of research in survivable flight control systems and increased the desirability of a side-arm controller. The success of anti-aircraft missiles against U.S. aircraft in Southeast Asia forced aircraft into a low altitude, high G, high-speed envelope. In addition the current hydraulic-power systems are highly susceptible to anti-aircraft fire. Thus a side-arm control stick as an integral part of a fly-by-wire system provides either a primary or backup control stick which is less vulnerable to combat damage and an improvement in tracking ability for the pilot under a high G load.

The literature search showed that the principal studies carried out on side-arm control sticks since 1967 has been under the cognizance of the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command. The research effort represents the bulk of the past and current effort on fly-by-wire systems and side-arm control sticks. For the most part the research has been carried out in flight tests in operational aircraft with a great reliance on pilot opinion. Emphasis has been placed in

the design of a multitude of configurations or side-arm control manipulators.

B. CURRENT STATE OF THE ART

In 1971, McDonnell Aircraft Company published a study which established design and performance criteria for side-arm control sticks. This report provides significant value to research efforts for the side-arm control stick in that the design and performance criteria were for the first time identified and phrased clearly for the purpose of co-ordinating research efforts toward specific objectives in evaluating mechanical and human engineering design concepts [Ref. 5].

While considerable efforts have been made in the past to test the suitability and feasibility of the side-arm control stick, the design and testing criteria have not been co-ordinated among investigators. Research efforts in side-arm control sticks have ranged from high performance jets to space ships based on a multitude of configurations of grips and installation locations in cockpits.

The McDonnell Aircraft Company side-arm control stick was designed for installation in the F-4 aircraft with due consideration for grip configuration, armrest and wrist support, neutral position adjustment, grip travel, breakout forces, artificial feel, total force gradient, and trigger actuating forces [Ref. 5]. The adverse attributes of the side-arm control stick in previous flight tests have shown that one or more of the factors mentioned above has been

influential in determining pilot opinions. Having incorporated the results of previous research efforts, the McDonnell Aircraft Company side-arm control stick would serve as an excellent reference tool not only in flight tests but for simulator studies in vibrations, fatigue, and tracking task tests.

IV. COLLECTED BIBLIOGRAPHY

This literature search resulted in a compilation of bibliography on side-arm control sticks and certain reports on the human engineering aspects of control sticks. All the literature was reviewed for content application and grouped into the following categories:

Category A = Performance and design tests conducted on side-arm control sticks (Appendix A).

Category B = Human engineering aspects applicable to aircraft control stick design (Appendix B).

Category c = Classified or restricted reports (Appendix C).

Certain reports obtained during the literature search were subject to special export controls and could not be released to foreign governments or foreign nationals. Therefore, only bibliographic information was listed for these reports and they were grouped into Category C. These reports were considered significant in their contribution to the total research efforts made on side-arm control sticks.

Each report was retrieved from a multitude of sources and was placed into archives of the Naval Postgraduate School to form a working collection of literature on side-arm control sticks.

The abstracted works listed in the appendices of this report cite only the significant literature concerning aircraft side-arm control sticks. Consequently, a vast amount of the literature retrieved has been purposely excluded from the abstracted bibliography. These works included research work on flight simulation, human dynamic response, statistical measurements of manual control systems, evaluation of pilot opinion, and the influence of variables such as environment and multiple tasks on tracking performance. By and large, these works were listed in the references of literature on side-arm control sticks.

V. CONCLUSIONS

The literature survey revealed that no definitive or efficient system exists for the location and retrieval of literature on aircraft control sticks. An update of the abstracted bibliography provided by this study will require a comprehensive monitoring of not only a multitude of services and sources but many activities and institutions concerned with aircraft flight control systems.

The principal research efforts are currently being conducted under the auspices of the Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base,

Ohio. These research programs are being conducted by numerous contractors in a coordinated effort to produce a survivable flight control system for fighter type aircraft and an operationally reliable fly-by-wire control system. Both programs are closely related and the side-arm control stick is an integral part of each investigation.

Previous flight tests conducted by a number of research activities have demonstrated the feasibility and suitability of a side-arm control stick in aircraft as a primary or secondary control stick. However, the design of side-arm control sticks in previous tests have contributed to problems in grip size, arm support, grip travel, breakout forces, force gradients, neutral position adjustment, and cockpit locations. The McDonnell Aircraft Company's effort in a survivable flight control system has produced a side-arm control stick which will facilitate future research efforts in coping with the problems encountered in previous investigations.

APPENDIX A

ABSTRACTED BIBLIOGRAPHY

PERFORMANCE AND DESIGN TESTS CONDUCTED ON SIDE-ARM CONTROL STICKS

Air Force Flight Test Center TN-56-24, An Evaluation of the Side Stick Control System, by R.M. White, November 1956, 35 p.

The side stick control is acceptable, although the majority of pilots prefer the conventional center stick installation. Disadvantages of the side stick system include the conflict with a long established flying habit, the retraining necessary with a new system, the requirement to operate all but the flight controls with the left hand, and the loss of the right hand console. These disadvantages must be weighed against those to be qained by making the center cockpit area available.

The installation as flown must be developed further before it is ready for production. An investigation should be made of the possible advantages of using a stick pivoted at the bottom of the grip with lateral motion for lateral control. If the present rotary motion is to be retained the grip must be made smaller and designed to fit the hand better. The trim control must be improved so that the grip is not moved when lateral trim is applied. A fore and aft sliding armrest with an adjustable height control is necessary to relieve arm fatigue and yield precise longitudinal control. The longitudinal break-out forces must be reduced below those encountered with a conventional stick. (Author)

National Advisory Committee for Aeronautics NACA RM L 56L28A, Flight Investigation of a Small Side-Located Control Stick Used with Electronic Control Systems on a Fighter Airplane, by S. A. Sjoberg, Walter R. Russell, and William L. Alford, 11 March 1957, 43 p.

A flight investigation was made to obtain pilots' opinions on the suitability of using a small stick mounted at the end of an arm rest at the pilot's side as the maneuvering flight controller for a fighter airplane. The stick used was about four inches long and was pivoted

at the bottom. Simple springs were used to provide centering and feel to the stick. The side-located control stick was used with both a rate automatic control system and an irreversible electronic power control system. Included in the flying were take-offs, landings, stall approaches, cruising, simulated air-to-air tracking, and aerobatics.

None of the 14 pilots who used the side-located control stick reported any difficulty in flying or controlling the airplane. Furthermore, the pilots were able to do precision flying such as tracking a non-maneuvering or mildly maneuvering target with good accuracy. In the pilots' opinion the controller was comfortably located and comfortable to use. The stick motions required were natural and the pilots became accustomed to the controller quickly. The pilots preferred to move the stick with finger and wrist motions rather than arm motions. A significant reduction of physical effort from that required for a conventional control stick resulted from use of the side-located controller. From a comfort and precision control standpoint the arm rest was considered to be essential. (Author)

National Advisory Committee for Aeronautics NACA TN 4171, Some Ground Measurements of the Forces Applied by Pilots to a Side-Located Aircraft Controller, by Roy F. Brissenden, November 1957, 17 p.

Ground test have been made to determine pilots' force capabilities on a proposed side-located aircraft controller, located at one side of the cockpit and situated so the pilot's arm may be supported. The axes of the controller are in a plane through the center of the pilot's forearm to minimize the effects of acceleration forces.

Results indicate a neutral position for the controller at 8° to the right and 15° forward of the vertical. The ability of the pilots to apply forces in both directions at various angles of roll and pitch indicated a usable range for the controller. At the limits of deflection suggested for the controller, the torque capability in the direction of increasing deflection was approximately one-half the maximum value. The range of deflection for roll control was $\pm 45^{\circ}$ from the neutral point. The range of deflection for longitudinal control was $\pm 22\ 1/2^{\circ}$ from the neutral point. Pilots participating in the tests indicated forces that they considered desirable for operation of the side-located controller. This operational torque for the controller is from 10 to 26 inch-pounds in roll and from 15 to 36 inch-pounds in pitch. The pilot's arm should be extended slightly forward of a 90°

elbow angle. In the range of deflection proposed for the controller, the relationship between maximum torque (applied in the direction to increase the deflection) and controller deflection is linear, with the torque decreasing in the direction of rotation. (Author)

National Advisory Committee for Aeronautics NACA RM L58B14, Ground Simulator Studies of a Small Side-Located Controller in a Power Control System, by Arthur Assodourian, 23 April 1958, 27 p.

An investigation was made to determine the operating characteristics of a small side-located control stick with the use of a ground simulator incorporating a power control system. The simulator or pitch chair was designed to produce the pitching motion associated with the short-period mode of an airplane. The short-period dynamic characteristics of the simulator were adjustable so that a large number of airplane flight conditions could be simulated. The quality of the control system using the side-located controller was determined by the ease and precision with which various tracking maneuvers could be accomplished by the pilot.

A general opinion of all the pilots operating the pitch chair was that they were favorably impressed with their ability to track precisely with the small side-located controller provided the control-system characteristics were desirable. The results indicated that an increase in the damping ratio, an increase in the period, or a decrease in the steady-state ratio of pitching velocity to angle of attack tended to improve the tracking performance. Changes in the period were made while the ratio of angle of attack to control deflection was held constant. Tracking ability was also improved by using the lower of two control sensitivities tested and by decreasing static stick friction. Where static stick friction was the limiting factor, about 3 pounds at the grip was found to be the tolerable limit for the side-located controller. (Author)

National Advisory Committee for Aeronautics NACA TN 4297, Flight Investigation of the Acceptability of a Small Side-Located Controller Used with an Irreversible Hydraulic Control System, by Helmut A. Kuehnel and Robert W. Sommer, July 1958, 19 p.

A flight investigation has been conducted to determine the acceptability of a small side-located controller which is used as the primary airplane controller in an irreversible hydraulic-power control system. The particular controller used in this investigation requires up and down hand motion pivoting at the wrist for

longitudinal control and lateral hand or forearm motion for lateral control. Pilot opinion was obtained concerning the acceptability of the controller while performing lateral and longitudinal maneuvers in a jet-trainer airplane at cruising-flight conditions.

The results of this investigation indicate that the location of the controller is consistent with pilot comfort and the airplane is flyable with the side-located controller. Hand motion about the wrist pivot required for longitudinal control is somewhat uncomfortable when large stick motions and high forces are required. Stick breakout force and stick force gradient should be kept at low values consistent with the reduced-force-output requirements of the pilot when operating a small side-located controller of the type used in this investigation. (Author)

Wright Air Development Center WADC Technical Note 59-253, Flight Investigation of a Minimal Manual Flight Control System Operated Through a Small Side-Located Control Stick, by O. Patrick Arquilla, June 1959, 74 p.

The minimal manual flight control system utilizes a small side-stick controller which operates the hydraulic control surface positioning system through a series of lightweight, low friction linkages. It was conceived as a simple and basic mechanical system which can serve, in its projected use, as an emergency "back-up" for an electrical flight control system.

The "minimal manual" elevon control system designed was qualitatively flight tested on JF-102A airplane, USAF S/N 54-1390. Tests were performed at Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, between 13 February and 28 April 1959. The program consisted of twenty-seven (27) flights, totalling thirty-three (33) hours and fifteen (15) minutes.

The flight test qualitative evaluation by fifteen (15) USAF Experimental Flight Test pilots and two NASA Aeronautical Research pilots reveals that the "Minimal Manual Flight Control System", in the configuration tested, is a satisfactory "get home" system. (Author)

Minneapolis-Honeywell Regulator Company, Minneapolis, Minnesota, Study and Development of an Electric Side Stick Controller for Aerospace Vehicles, by H.C. Graves, A.J. Bailey, and D.I. Mellon, May 1962, 52 p.

This document describes the engineering program conducted under USAF sponsorship on an electric side

stick controller for advanced aerospace vehicles. The immediate objective of the program was to develop an electric side stick controller for the X-15 Research Vehicle which was compatible with the MH-96 Adaptive Flight Control System. A secondary and more general objective was to develop empirical data on the human engineering aspects of side stick controller design which would be applicable to more advanced aerospace vehicles.

The program included extensive flight test evaluations in a JF-101A aircraft. Excellent experimental results were obtained during the course of the program, leading to a concrete specification for electric side stick for the X-15 research vehicle.

New areas of side stick performance which needed investigation became apparent during this study but they were outside the scope of this study. These areas, such as low L/D landings, pencil stick performance, and adaptive model variations, are discussed.

The development of the electric side stick was closely related to the features and characteristics of the Honeywell Adaptive Flight Control System, therefore, an Appendix, "Adaptive Flight Control Concepts", has been included in this report for background information. (Author)

Naval Air Test Center Technical Report FT2123-62R-64, Flight Evaluation of a Side Hand Controller in an F-4A Airplane, Final Report, by T. M. Kastner and R. H. Soderquist, 15 October 1964, 51 p.

A side hand controller using palm pressure forces to provide electrical pitch and roll control signals to a self adaptive control system was evaluated in an F-4 airplane. Acceptable and optimum controller characteristics were determined. Seven pilots participated in a comparative evaluation of the hand controller and center stick using both controlled test maneuvers and operational maneuvers such as gunnery tracking, LABS, and mirror landings as standards. The hand controller was found to be inferior to the center stick because of over specialization of control, inadequate deflection cues, incompatibility with auxiliary switches, and lack of pilot acceptance of the controller in the performance of maneuvers. The controller did offer a certain ease and naturalness of operation, and its use should be considered in the design of space vehicles. Tests also emphasized various control system and flying qualities deficiencies which should be corrected in the design of future self adaptive systems. Salient deficiencies were: the need

for specific actuator response characteristics, performance deterioration with airframe vibrations, and spin susceptibility. (Author)

U.S. Naval Postgraduate School, M.S. Thesis, Development of a Simulator For the Evaluation of Rigid and Movable Aircraft Controls, by D.W. Caswell, June 1969, 48 p.

A simulator was constructed with two sets of aircraft controls; one set was movable and one set was rigid. The control output signals were integrated into an analog computer circuit to provide the desired aerodynamic characteristics. A repeatable, random input voltage to an oscilloscope was used as a basis for a tracking exercise in which the test subject, by manipulation of the control stick, attempted to cancel the random signal. A scoring method was devised which utilized an electonic counter and signal comparator to evaluate pilot performance with each of the four control sticks. (Author)

Cole, James Daniel, A Pilot Evaluation of Movable and Rigid Aircraft Controls, M.S. Thesis, U.S. Naval Postgraduate School, Monterey, California, June 1970, 81 p.

A simulator facility employing a two-axis compensatory tracking task with a random-appearing signal was used to evaluate the performance of fifty-five pilot and non-pilot test subjects using four separate control sticks...two movable and two rigid. Pilot acceptance of the rigid cockpit controllers was determined by comparing individual pilot ratings of the sticks. (Author)

Layton, Donald M., A Simulator Evaluation of Pilot Performance and Acceptance of an Aircraft Rigid Cockpit Control System, July 1970, 96 p. U.S. Naval Postgraduate School Technical Report NPS-57LN70071A.

A ground-based simulator facility employing a two-axis compensatory tracking task with a random appearing signal was used to evaluate the performance of one hundred five pilot and non-pilot test subjects using four separate control sticks...two moveable and two rigid. Pilot acceptance of the rigid cockpit controllers was determined by comparing individual pilot ratings of the sticks. In general, in both performance and opinion, the rigid systems were found to be superior to their moveable counterparts. Steps were taken to avoid errors due to pilot bias, learning, fatigue, or adaptation. The results obtained are subject to several test limitations, including the low stick-force levels employed,

the lack of aircraft vibration effects, and the realism of the simulation. (Author)

The Society of Experimental Test Pilots, 1970 Report to the Aerospace Profession, F-104D Side Stick Control System, symposium proceedings, Beverly Hills, California, by E. W. Theurer and K.E. Staten, 24-26 September 1970, SETP Technical Review, v. 10, p. 198-253.

The Aerospace Research Pilot School (ARPS) contracted with Martin Marieta Corporation's Baltimore Division to design, build, and install a side stick fly-by-wire control system in a two-seat F-104D aircraft. The design was tested in-flight and it was verified that the system will accomplish all the maneuvers in the ARPS curriculum.

The major conclusions were that the side stick is usable and offers improvements for aircraft control, pilot selectable gains, force gradients, and viscous damping should be included in future designs of control sticks, switches on a side stick must have physical displacement and actuation forces well below the controller breakout forces, two controllers will be required for operational use, and arm rest adjustment must be incorporated to account for size of pilot's hand and bulk of garments.

General Precision, Link Group, Binghamton, N.Y., A Comparison of Pilot Performance Using a Center Stick Versus Sidearm Control Configuration, Technical Report ASD-TR-70-39 by R. Geiselhart, P. Kemmerling, J.G. Cronburg, D.E. Thorburn, November 1970, 45 p.

Six Air Force pilots having current flying status flew a series of forty-minute missions to compare pilot performance with the conventional center stick, dual side stick, and single side stick configurations. An F-111 flight simulator with three degrees-of-motion was employed as the test-bed for the experiment. The missions, which included climbout, a terrain following portion, two banking turns, and five Instrument Landing System (ILS) approaches, were designed to test the feasibility of side stick controllers under low-altitude, high-speed conditions. Course steering deviation, pitch deviation, and ILS evaluation scores were obtained using the three stick configurations. From the evaluations of the performance data and opinion questionnaires filled out by the pilots, it was concluded that side stick controllers are feasible for use in a relatively high-speed aircraft flying a low-altitude, high-speed mission,

and that dual side sticks are preferable to single side sticks. Recommendations were made for further studies in several areas. (Author)

McDonnell Aircraft Company, McDonnell Douglas Corporation, Survivable Flight Control System Interim Report No. 1 Studies, Analyses and Approach, Technical Report AFFDL-TR-71-20 by D.S. Hooker, R.I. Kisslinger, G.R. Smith, and M.S. Smyth, May 1971, 355 p.

The Survivable Flight Control System (SFCS) Program is an advanced development program of which the principal objective is the development and flight test demonstration of an SFCS utilizing Fly-By-Wire and Integrated Actuator Package techniques. The studies and analyses conducted to date have sufficiently defined to the implementation of the SFCS. The results of these studies and the definition of the approach are presented herein. The details of the Control Criteria, Control Law development, and Hydraulic Power and Actuation Studies are presented in report supplements 1,2, and 3 respectfully.

The SFCS Program is based on the principle of dispersed redundant control elements providing improved control performance and a very stable weapons delivery platform. The SFCS equipment includes:

1. A quadruplex, three-axis, two-fail operational Survivable Flight Control Electronics Set which provides the computations for fly-by-wire control. Preflight built in test, in-flight monitoring of SFCS equipment, an adaptive gain and stall warning function, and provitions for in-flight failure simulation are included.

2. Quadruplex force-summing electrohydraulic secondary actuators to convert the fly-by-wire flight control signals into the physical motion required to command the existing power actuators of the F-4 test aircraft.

3. A quadruplex, two-axis sidestick controller in each cockpit. The front cockpit will also provide fly-by-wire center stick to allow direct comparison.

4. A duplex power-by-wire actuator termed the Survivable Stabilator Actuator Package (SSAP). The SSAP will be capable of full-time operation throughout the F-4 flight envelope while receiving only electrical power. The SSAP incorporates a quadruplex velocity-summing electromechanical secondary actuator, and is controlled solely by the fly-by-wire system. (Author)

McDonnell Aircraft Company, Survivable Flight Control System Interim Report No. 1 Studies, Analysis and Approach, Technical Report AFFOL-TR-71-20 Supplement 2, by R.L. Kisslinger and C.J. Vetsch, May 1971, 333 p.

The Survivable Flight Control System (SFCS) Program is an advanced development program of which the principal objective is the development and flight test demonstration of an SFCS utilizing Fly-by-Wire and Integrated Actuator Package techniques. The studies and analyses conducted to date have sufficiently defined the system requirements to provide a definition of an approach to the implementation of the SFCS. The results of these studies and the definition of the approach are presented in the basic report. The details of the Control Criteria, and Hydraulic Power and Actuation studies are presented in report supplements 1 and 3, respectively. The results of the Control Law Development studies are presented in this supplement 2.

A mockup of the LSI side stick controller was evaluated during simulation. It was used to perform the various tasks and found to be an acceptable flight controller. The pilots felt the breakout forces of ± 2.5 pounds were too high. A reduction to ± 1.75 pounds was found more desireable. More time for familiarization with the actual side stick hardware during flight tests will be required before valid comparisons between the controllers can be made. A time history of a landing approach using the side stick controller in the Normal mode is presented. Cumulative distribution shows that the side stick is an effective flight controller for landing approach. The pilots used the side stick for other tasks and found it useable in all cases. Only during the rapid attitude changes required during the air-to-air tracking did the pilots tend to over control with the side stick.

APPENDIX B

ABSTRACTED BIBLIOGRAPHY

HUMAN ENGINEERING ASPECTS OF CONTROL STICK DESIGN

National Advisory Committee for Aeronautics Technical Note Number 550, Limitations of the Pilot in Applying Forces to Airplane Controls, by M.N. Gough and A.P. Beard, 1936, 13 p.

Measurements were made to determine the relative maximum forces a pilot can exert on the controls of an airplane with a view to obtaining systematic data upon which to base the location of controls within the cockpit and the design of the control surfaces. A cockpit model of generous proportions, capable of being rotated to any attitude, was built with the location of the control stick and rudder pedals adjustable over a wide range of positions with respect to the seat. Besides measurements of maximum forces obtainable with various control locations and with the pilot in several attitudes, estimates of forces within the range normally encountered in flight were made to gain an indication of the accuracy of estimating control forces. No accelerations were imposed upon the pilot while the data were being obtained.

The measurements indicated that: the lateral push possible on the stick is greater than the pull and both decrease fairly uniformly with increasing distance of the stick from the seat; the longitudinal pull on the stick increases with increasing distance of the stick from the seat and is greater than the push except in rearmost positions; for the range of positions tested there is a slight increase in the force that can be applied as the height of the stick above the seat is increased; there is a pronounced peak in the variation of rudder force with distance of the rudder pedals from the seat; when the pilot is securely fastened to the seat, the attitude has little effect on the forces that he can apply the most force to the controls; estimation of control forces is most accurate for intermediate forces.

The maximum aileron forces measure were of the order of 90 pounds, maximum elevator 200 pounds, and maximum rudder 450 pounds. The average forces applied with the controls in the neutral position for the various cockpit

attitudes were of the order of 35, 95, and 400 pounds, respectively, for the airlerons, elevators, and rudder. (Author)

Psychological Corporation, New York, The Human Factor in the Design of Stick and Rudder Controls for Aircraft, by Jack W. Dunlap, 3 February 1948, 80 p.

The study is an attempt to determine how airplane control systems may be designed to provide the pilot with optimal sensory information by means of pressure cues obtained from operating the stick and rudder. The present approach to the problem consists of an examination and evaluation of literature pertaining to (a) the maximum forces that may be exerted by a human pilot; (b) human reaction time insofar as it may be expected to cause delays in the pilot's response; (c) the optimal design, placement, and manner of movement of controls, and (d) the optimal gradients of control forces. (Author)

Orlansky, Jesse, "Psychological Aspects of Stick and Rudder Controls in Aircraft," Aeronautical Engineering Review, v. 8, p. 22-31, January 1949.

This paper is an attempt to determine how airplane control systems may be designed to provide the pilot with optimal sensory information by means of pressure cues obtained from operating the stick and rudder. The present approach to the problem consists of an examination and evaluation of literature pertaining to:

(a) The maximum forces that may be exerted by a human pilot.
(b) Human reaction time insofar as it may be expected to cause delays in the pilot's response.
(c) The optimal design, placement, and manner of movement of controls.
(d) The optimal gradient of control forces.

Certain recommendations for aircraft control systems are discussed. (Author)

Bureau of Aeronautics BUAER Report AE-61-4 III, The Human Pilot, by Servomechanisms Section, Mechanical Design Department, Northrop Aircraft, Inc., August 1954, 1 v. (various pagings) BuAer Contract NOas 51-514(c)

The report was concerned with the mechanism by which a pilot senses stimuli and actuates controls, and with quantitative dynamic properties of this mechanism, such as thresholds of preception, limits to forces which can be applied, reaction-time delays, etc. It described the

results of recent attempts utilizing existing techniques to develop mathematical models or network analogies of the human pilot which engineers can use to predict the responses made by pilots in controlling airplanes. (Author)

Rome Air Development Center Technical Note 55-376, Speed of Target Acquisition as Functions of Knob vs. Stick Control, Positioning vs. Velocity Relationship, and Scoring Tolerance, by B.G. Andreas, D.P. Murphy, and S.D.S. Spragg, Department of Psychology, University of Rochester, July 1955, 20 p.

This experiment compared the speed of target acquisition of stationary targets (in a situation presenting display and control characteristics analogous to certain radar tasks) as functions of the following variables: (1) two know controls vs. a miniature X-Y stick control; (2) positioning vs. velocity mode of tracking; and (3) a large vs. a small on-target tolerance.

Eight young adult male subject were trained in a series of eight sessions which represented the permutations of the several experimental conditions. Each session consisted of eight trials, and in turn each trial consisted of 25 target acquisitions.

Three time measures of performance were analyzed: movement time, settling time, and total time. The resulting performance curves showed considerable improvement as a function of practice for velocity tracking over the first four or five trials, but relatively little thereafter. Evidences of improvement for position tracking were slight. For all conditions performance was relatively stable by the eighth trial.

Statistical analysis was based upon performance on the eighth trial only, and yielded the following results:

1. The two-knob control was significantly superior to the X-Y stick control used. This superiority was greater for the smaller of the two on-target tolerances used, and was due mainly to differences in settling time rather than movement time.

2. Position tracking was significantly superior to velocity tracking on this task, for both large and small on-target tolerances, for knobs as well as stick control, and for movement time as well as settling time. (Author)

National Advisory Committee for Aeronautics Technical Note 3998, Ground Simulator Studies of the Effects of Valve Friction, Stick Friction, Flexibility, and Backlash on Power Control System Quality, by B. Porter Brown, April 1957, 14 p.

Tests have been made on a power control system by means of a ground simulator to determine the effects of various combinations of valve friction and stick friction on the ability of the pilot to control the system. Various friction conditions were simulated with a rigid control system, a flexible system, and a rigid system having some backlash. For the tests, the period and damping of the simulated airplane were held constant.

The results show that, when valve friction was present in a rigid system, the introduction of stick friction was beneficial in that it restored some of the quality lost because of the valve friction. When flexibility was introduced between the pilot and the source of stick friction, stick friction was still beneficial but, with flexibility between the source of stick friction and the valve, no benefits were obtained from stick friction. When backlash was introduced between the pilot and the source of stick friction, the valve-friction effect was not so objectionable as in the rigid system; stick friction improved this system still further. With backlash between the stick and the valve (0.025 inch at the valve), even the frictionless system was undesirable, and the addition of any combination of the frictions reduced the control quality still further. (Author)

Kohlhaas, Richard Lewis, Limits of Pilot Controllability of a Two-Axis Unstable, Second-Order System, M.S. Thesis, Institute of Technology, U.S. Air Force Air University, Wright-Patterson Air Force Base, Ohio, 1962, 47 p.

Previous research has shown that the human operator can be represented as an element in an overall closed-loop servo system which includes the dynamics of the vehicle. Transfer functions for the operator have been determined by experimentation. The present study experimentally determined the limits of controllability of two, non-pilot, previously untrained, human operators in simulated compensatory-type two-axis control situations. The two controlled elements were identical second-order, unstable, oscillatory systems. The limits are defined as the maximum controlled element natural frequency at a given damping ratio for which the operator is able to maintain both system error signals within $\pm$ 1 inch visible boundaries for two successive periods of 120 seconds. The limits were characterized by a generally constant product of natural frequency and damping ratio

for damping ratios of -.11, -.22, -.35, and -.70. The product was -.35 radians per second for one operator; from -.42 to -.49 for the other. The operator output signal, transmitted through a two-axis aircraft-type control stick, was in the form of discrete pulses which were never applied to both systems simultaneously. A general constant error for both high and low degrees of instability was noted. Pursuit and semi-precognitive modes of operation were observed for damping ratios of -.11 and -.22. The control technique appears to be a semi-open-loop nature. An analysis of one sampled-data model of the situation, using an operator transfer function determined from the results of a similar single-axis experiment, does not correlate with the observed operator limits. (Author)

National Aeronautics and Space Administration NASA TN D-102, Flight Investigation of a Centrally Located Rigid Force Control Stick Used with Electronic Control Systems in a Fighter Airplane, by Walter R. Russell and William L. Alford, September 1959, 30 p.

A flight investigation was made to evaluate a rigid, non-moving, centrally located force stick as a maneuvering flight controller for a fighter airplane. The force stick was similar in size and location to a conventional control stick and was used with both a rate-type command control system and in irreversible electronic power control system. Included in the flying were pullups, turns, aileron rolls, rough-air flying, stall approaches, and landing.

In the opinion of the pilots the centrally located rigid force stick was not as suitable for use as a maneuvering controller for a fighter airplane as a displacement-type control stick. Although the pilots did not find the lack of stick displacement to be greatly objectionable, they were of the opinion that some stick motion was desirable.

The longitudinal control characteristics were satisfactory. No longitudinal sensitivity problems were encountered. The pilots preferred a stick force gradient of about five pounds per G except at indicated airspeeds below 150 knots where the preferred force gradient was slightly higher.

The lateral control characteristics generally were unsatisfactory. At indicated airspeeds above 150 knots the pilots found it difficult to maintain a constant rolling velocity. The undesired rolling motions were evident primarily as low-amplitude variations in rolling acceleration. The undesired rolling accelerations were

annoying to the pilot and made precision flying difficult. They resulted from the lack of stick displacement, lack of stick friction, and the short response time of the control-system--airplane combination. (Author)

Air Force Flight Dynamics Laboratory Technical Documentary Report ASD-TDR-63-85, The Statistical Properties of Signals and Measurements of Simple Manual Control Systems, by Jerome I. Elkind and D. Lucille Darley, Bolt Beranek and Newman Inc., Cambridge, Mass., July 1963, 38 p.

The distribution functions of the amplitudes of the signals flowing in a simple compensatory manual control system and of the transfer functions and power spectra used to describe the characteristics of the system were measured when the system was excited by a variety of different gaussian input signals. For very low and very high bandwidth signals there is some indication that the error and remnant (the part of system response not linearly correlated with the input) signals may not be normal. The openloop transfer function for the human operator expressed in terms of log magnitude and phase was found to be approximately normal. The error and remnant power spectra were found to be distributed approximately as X^2. (Author)

Bird, Daniel, "Flight Control Studies in the Small Stick Deflection Area," Journal of Aircraft, p. 121-125, May-June 1964.

The relative effects of control-system friction, preload, back-lash, gearing, force gradient, damping, and trim rate on handling qualities in the small stick deflection area are investigated. The nonlinear variables of friction, preload, and backlash are given the most attention. A fixed-base, analog-computer flight simulation, with provisions for varying the control-system properties of interest in a carefully defined manner, is used for the investigation. Scoring is accomplished by direct quantitative measurements, in addition to pilot Cooper Rating, and a unique performance-measurement parameter (g-ft-lb) is developed. It is concluded that friction is the most important control-system property in the small deflection range of flying.

Systems Technology, Inc. Technical Report APFDL-TR-66-138, Human Pilot Dynamics with Various Manipulators, by D.T. McRuer and R.E. Magdaleno, December 1966, 42 p.

The purpose of the experimental efforts reported here is to explore on a preliminary basis the limiting characteristics of the human operator's "actuator" or neuromuscular system dynamics as affected by the manipulator. The effects of three manipulators (pressure, free-moving, and spring-restrained) on system performance and the human operator's describing function are presented for three controlled elements and two high bandwidth forcing functions. Describing function differences are primarily in the phase, i.e., the effective time delay at high-frequency and an effective phase lag at very low frequencies.

Generally the mean square error and describing functions results for the spring-restrained manipulator were intermediate to those for the free-moving (no spring) and the pressure (infinite spring) manipulators. The pressure controller gave lower mean square error and less effective time delay than the free-moving controller. In addition, the effective phase lag at very low frequencies was either the same as or larger than that for the free-moving control (Author)

Air Force Flight Dynamics Laboratory Technical Report AFFDL-TR-66-72, Effects of Manipulator Restraints on Human Operator Performance, by R.E. Magdaleno and D.T. McRuer, Systems Technology, Inc., December 1966, 47 p.

This report is concerned with a series of experiments in which the effects of manipulator restraints, i.e., load dynamics imposed on the pilot, are central. The purpose of this investigation are to:

1. Determine the load effects on the pilot's describing functions and performance measures for a representative variety of manipulator restraints and controlled elements.

2. Provide inferential insight into the relative importance of limb position and output force senses in manual control.

The results indicate that the pilot performs best with a spring restrained manipulator. With pure inertia restraint there is a large performance degradation unless the inertia is less than that given by the pilot's output limb acting on the manipulator. Generally, the pilot has good position feedback in that his describing function form is essentially invariant to a wide range of spring and inertia restraints for the same controlled element. (Author)

APPENDIX C

CLASSIFIED OR RESTRICTED REPORTS

1. Fir Force Flight Dynamics Laboratory, Fly-By-Wire Flight Control Systems (U), by J.P. Sutherland, 10 August 1967, 33 p., NOFORN.

2. Air Force Flight Dynamics Laboratory AFFDL-TR-68-72, Development of Three Improved Primary Flight Controller Designs (U), by R.N. Winner, July 1968, 29 p., NOFORN

3. Bell Aerosystems Company, Buffalo, N.Y., Flight Test Evaluation of a Two Axis Side Hand Controller in a High Performance Aircraft (U), by M.F.N.J. Carriero and F.D. Lane, September 1964, 68 p. NOFORN

4. Douglas Aircraft Company, Long Beach, California, Report Number LD 31050, Contract Number NONR 107600, Effects of Static Friction and Force-Displacement Gradient on a Discrete Visual Tracking Task (U), by J.F. Watler, June 1963, 107 p. NOFORN

5. Hydraulic Research and Manufacturing Company Technical Report AFFDL-TR-69-119, Volume II, Research on Flight Control Systems Fly-By-Wire B-47 Phases II and III, (U), By G.D. Jenney, August 1970, 169 p. NOFORN.

6. Hydraulic Research and Manufacturing Company Technical Report AFFDL-TR-69-119, Volume III, Research on Flight Control Systems Volume III, Fly-By-Wire Techniques (U), by D.G. Bazill and G.D. Jenney, October 1970, 143 p. NOFORN.

7. Minneapolis-Honeywell Regulator Company, Minneapolis, Minnesota, Technical Report No. ASD-TR-61-603, Study and Development of an Electric Side Stick Controller for Aerospace Vehicles (U), by H.C. Graves, A.J. Bailey, and D.I. Mellon, May 1962, 52 p. NOFORN.

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11. Sperry Flight Systems Division Sperry Rand Corporation Technical Report FFFDL-TR-69-9, A Prototype Fly-By-Wire Flight Control System (U), by J.E. Emfinger, August 1969, 131 p., NOFORN.

GLOSSARY OF ACRONYMS

1.	AGARD	Advisory Group for Aeronautical Research and Development
2.	ARPS	USAF Aerospace Research Pilot School
3.	ASTIA	Armed Services Technical Information Agency
4.	CCM	Current Index to Conference Papers: Science and Technology
5.	DDC	Defense Documentation Center
6.	IAA	International Aerospace Abstracts
7.	NACA	National Advisory Committee for Aeronautics
8.	NASA	National Aeronautics and Space Administration
9.	NTIS	National Technical Information Service
10.	STAR	Scientific and Technical Aerospace Reports
11.	TAB	Technical Abstract Bulletin
12.	USGRDR	U.S. Government Research and Development Reports

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13. ABSTRACT

An expanding interest at the Naval Postgraduate School, Monterey, California, in research work on aircraft side-arm control sticks has necessitated the determination of the previous and ongoing projects involved with the development of side-arm control sticks. This paper presents a survey of the English language literature dealing with aircraft control sticks over the period of 1936 to 1971. The result of the survey is an abstracted bibliography of significant literature related to the design and testing of aircraft control sticks and a guide to the literature.

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